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Short Note

Acoustic Activity of Harbour Porpoises *(Phocoena phocoena)* Around Gill Nets

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The harbour porpoise (*Phocoena phocoena*) is the only cetacean regularly found in the inner Danish and Swedish waters (Teilmann et al., 2008). Previous studies have estimated very high levels of bycatch of this species on the order of thousands yearly in the Danish and Swedish gillnet fisheries (Berggren, 1994; Vinther, 1999; Vinther & Larsen, 2004). In past decades, there has been a keen interest in finding means to reduce this bycatch. A major result of these efforts has been the development of acoustic alarms, so-called pingers. Pingers have been reported to deter harbour porpoises from nets (Cox et al., 2001; Culik et al., 2001) and to efficiently reduce bycatch (Kraus et al., 1997; Larsen et al., 2013). Although previous studies indicate that harbour porpoises can detect gill nets at sufficient distance to avoid them (Kastelein et al., 2000; Koschinski et al., 2006; Villadsgaard et al., 2007; Nielsen et al., 2012), for unknown reasons they are still being caught in nets both with and without pingers (Dawson et al., 1998). In addition, there may be several potential problems with a large-scale use of pingers such as habituation and noise pollution. As an alternative, new types of fishing nets that are easier to detect by the harbour porpoises may potentially be a solution (Trippel et al., 2003; Cox & Read, 2004; Koschinski et al., 2006; Mooney et al., 2007).

When developing such mitigation measures, it is important to know at which distances harbour porpoises can detect fishing gear and how they react to them. For example, the development of alternative high-density nets is much more efficient if it is known to what extent harbour porpoises can detect nets made of different types of material. Likewise, the design of efficient pingers is augmented by knowledge about how harbour porpoises react to different sounds. In addition, understanding harbour porpoise behaviour around fishing nets may improve our understanding of why harbour porpoises are sometimes being caught.

There are several methodological problems when investigating harbour porpoise movements around active fishing gear: the behaviour of harbour porpoises is difficult to monitor, and it is difficult to simultaneously keep track of the animal and the location of fishing nets. An efficient way to accommodate this is to detect the presence of harbour porpoises by listening for their echolocation clicks. Harbour porpoises produce intense ultrasonic clicks for echolocation (Møhl & Andersen, 1973; Verfuß et al., 2005, 2009). Normally, they emit some tens of clicks/s, but as they come closer to the target, the clicking rate increases to several hundred clicks/s (Villadsgaard et al., 2007; Verfuß et al., 2009). Their clicks have a frequency range of 110 to 150 kHz, a -10 dB duration of 44 to 113 µs, and a source level of 140 to 200 dB re 1 µPa pp @ 1 m (Villadsgaard et al., 2007). The signals are emitted in a cone-shaped beam of 11 to 13º opening angle (measured as the -3 dB limits re on axis; Koblitz et al., 2012). An underlying assumption when studying harbour porpoise behaviour using acoustic loggers is that the prevalence of detected harbour porpoise clicks reflects the number of present harbour porpoises. This assumes that harbour porpoises are clicking more or less continuously, which seems to be the case from the rather scarce data presently available (Linnenschmidt et al., 2012).

To investigate if harbour porpoise presence is different when introducing gill nets, we measured the click behaviour using acoustic loggers (Porpoise Click Loggers [PCL], Aquatech, Inc., UK). The PCL registers presence of acoustic signals with a hydrophone. The output from the hydrophone (sensitivity -208 dB re 1 V/µPa) passes through two 24 dB/octave band-pass filters (bandwidth 30 kHz) centred at 60 and 130 kHz. If the ratio of the signal amplitudes at the output of the 130 and 60 kHz filters is higher than a predefined integer, the signal is registered as coming from a harbour porpoise, given that the duration (measured as the duration of the part of the signal surpassing the set threshold) and click repetition rate of the extracted clicks are within some predefined intervals. Given the source level and propagation loss of harbour porpoise echolocation clicks (e.g.,Villadsgaard et al., 2007) and the detection threshold of the data loggers (around 140 dB re 1 µPa p), the loggers can pick up these signals at a range of several hundreds of meters. Harbour porpoises are able to detect fishing gear at somewhat shorter, but still comparable, ranges (presumably using acoustic cues; see Nielsen et al., 2012).

The underlying null hypothesis of this study was that the number of acoustic detections remains the same whether a net was present or not. Assuming that harbour porpoises emit clicks almost continuously, this means that the null hypothesis indicates there is no difference in the harbour porpoise distribution due to the net, and therefore, we may conclude that the harbour porpoises are not attracted or deterred from the net. If the hypothesis can be statistically rejected, however, the harbour porpoises are being either attracted or deterred by the fishing gear.

The PCL loggers can be programmed with different parameters that are used in the detection process of harbour porpoise clicks. The following settings were used:

- *Threshold for Comparator -28 dB* – This is the threshold for detecting the peak of a signal and corresponds to a received level of about 140 dB re 1 µPa p (depending on the specific sensitivity of each logger).
- *Ratio 2 to 255* – This is the ratio between the peak output of the 130 and 60 kHz filters and should be within this range for the positive detection of a harbour porpoise click.
- *Click Length 30 to 600 µs* – The duration of the click, measured as the interval in which the click is above the threshold, should be within this range. This range is much larger than the actual duration of harbour porpoise clicks (e.g., see Villadsgaard et al., 2007). The reason for this is to be able to detect clicks with a low received level as these will have a short duration due to the way the duration is measured. In addition, allowing for a long click length makes it possible to include click detections in which the direct and reflected paths are interfering, creating a signal which is of a longer duration than the direct sound path only.
- *Inter-Click Length 2 to 500 ms* – The inter-click interval (ICI) between two consecutive detections should be within this interval. The interval is larger than the ICIs expected from a harbour porpoise (e.g., Villadsgaard et al., 2007) to allow for the detection of harbour porpoises wherein some clicks will go undetected and therefore create an apparently large interval between clicks.

Several consecutive clicks emitted in a series are denoted as a *click train*. During analysis of the logged data, click trains can be detected from a set of criteria, and how many clicks are needed to define a click train can be established. By measuring the ICIs (the interval between two consecutive clicks), we can estimate the ICI ratio, which is the ratio between two consecutive ICIs. Any change in ICI between two consecutive clicks is assumed to be small for harbour porpoise click trains. The specific settings in the train detection menu in the analysis software (*AquaClickView*, Version 1.6b) were as follows:

- *Minimum Number of Clicks* – There should be at least 10 consecutive clicks within 500 ms.
- *Negative Change in ICI Ratio Between 0 and 0.95* – The range of allowed negative change in the ICI ratio between two consecutive clicks.
- *Positive Change in ICI Ratio Between 1.05 and 2* – The range of allowed positive change in the ICI ratio between two consecutive clicks.
- *Amplitude Ratio from 0 to 0.9 and 1.1 to 2* – The change in amplitude ratio between two consecutive clicks.

These settings were chosen based on known harbour porpoise click characteristics in order to maximize the detectability of harbour porpoise clicks, and all data loggers used the same parameters. Tests using the loggers on the harbour porpoises in captivity at Fjord&Bælt, Kerteminde, Denmark, convinced us that these parameters secured the detection of close-by harbour porpoises, likely up to a distance of several 100s of meters.

Before field trials, the sensitivity of loggers were measured in a 3 m deep and 3 m diameter test tank. A synthetic ultrasonic pulse was generated by an Agilent 3320A waveform generator and transmitted with a Reson 2130 transducer to the logger. The signal had a source level of 160 dB re 1 µPa pp @ 1 m, was 50 µs long, and centred at 130 kHz. Both the time series and the spectrum of the signal as measured at the location of the PCL was very similar to the signals generated by harbour porpoises at a distance of up to 100 m (Villadsgaard et al., 2007). A calibrated B&K 8103 hydrophone was used to measure the sound level at the data logger during the calibrations. The sensitivity varied with ± 6 dB between the loggers, and for the same logger there was a maximum ± 5.5 dB variation in sensitivity, depending on direction. Even though it was not possible to explicitly test the performance of the data loggers at the actual field site, we assume that their performance was similar to the one measured in the test tank.

Field work was carried out in the Kattegat (N 56° 49; E 12° 21). In all trials, two PCLs were placed at each end of a net or string of net panels, 1 to 2 m from the bottom (Figure 1). During each deployment, two additional loggers were placed in an area with the same bathymetrical conditions with no net as controls (Figure 2). These loggers were spaced similar to the net loggers (Figure 1). The controls were located more than 1.8 km from any fishing gear. The species composition of fish was very similar between areas where nets were deployed and in the control areas (Hammar et al., 2008).

Nets were usually deployed in the mornings, and each deployment lasted from 13 to 71 h. Each net consisted of a string of two net panels. One was a 45 m long—a so-called "research net" (Nordic model, Survey net Coastal)—1.8 m high, consisting of nine panels, each 5 m long, with varying bar mesh sizes: 30, 15, 38, 10, 48, 12, 24, 60, and 19 mm. The other was a 70-m long commercial net targeting turbot (*Psetta maximus*; monotwist 3 strands with 0.2 mm diameter) with bar size of 120 mm, and a maximum height of 1.8 m. No harbour porpoises were bycaught during the trials. Observations were carried out from 27 June to 18 July 2008 at water depths between 20 and 25 m. The bottom consisted of clay but was in association with sandy sea floor.

Data were downloaded with *USB 2.0* to a laptop using the program *AQUAtalk* (Version 2.12, Aquatech Group Ltd.). Files were opened with *AQUAclickView* (Version 2, Aquatech Group Ltd.). Seven of the recorded files included smaller problems with storing the real-time information of deployments, but these could be repaired using the program *AquaClickFileViewer* (Aquatech Group Ltd.).

The raw data files contained amplitude (after passing both filters) and the duration of each detected click. The further click train analysis sorted out the clicks in trains as defined above. The number of click trains detected per 10 s of data was saved as an ASCII file and imported into *Excel* and from there into text files imported into *Matlab* (Version 6.5). The first and last hour of recordings (right after and right before deployment and retrieval) were omitted to exclude the effect of noise from the fishing boat used for deploying the PCLs. The click trains were analysed to assess the number of harbour porpoise encounters. It was assumed that harbour porpoise click trains detected within a predefined duration of sampling, 5 min, have been caused by the same harbour porpoise (or harbour porpoise group). The duration of 5 min was used from what is known of harbour porpoise swimming behaviour from other studies performed by the authors and from the literature (e.g., Koschinski et al., 2006; Nielsen et al., 2012). Thus, a harbour porpoise encounter was determined as one or several click trains contained within a 5-min window, with an additional encounter occurring only if there was a pause longer than 5 min to the next train detection.

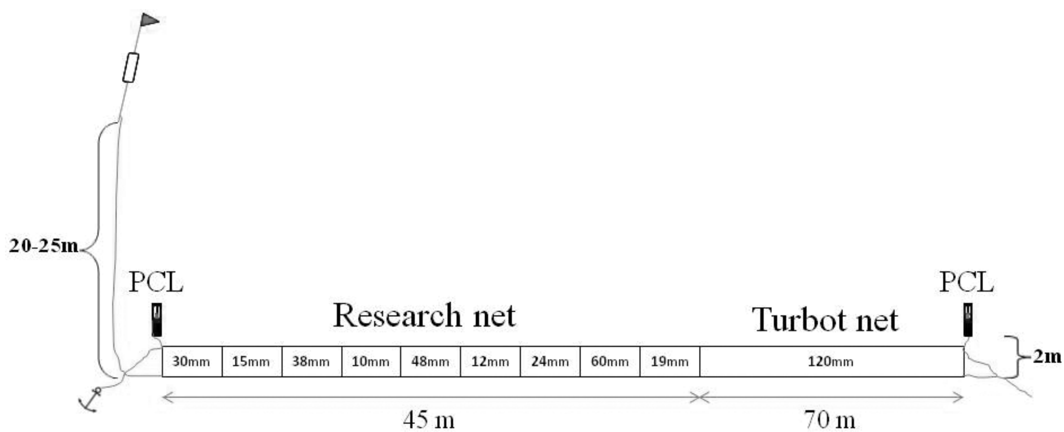

Figure 1. Harbour porpoise acoustic data loggers mounted at each end of a panel of different mesh-sized gill nets as explained in the text; PCLs mounted without a net were placed at similar distances in the representative control area.

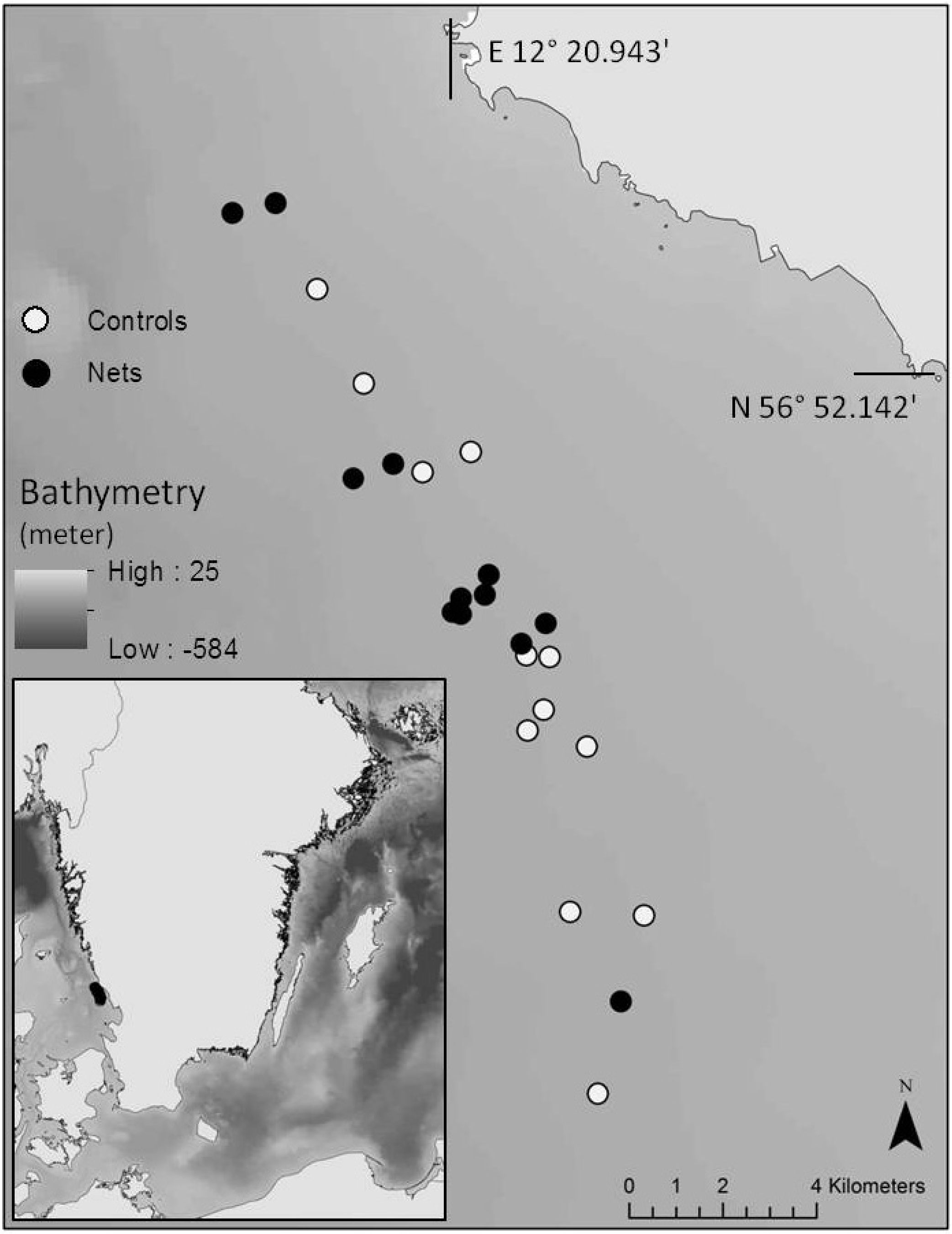

Figure 2. Locations of data loggers with and without nets (controls); bathymetric data from Al-Hamdani et al., 2007.

To test if harbour porpoises encounter PCLs attached to nets more often than PCLs away from any net and if there was a difference in the duration of presence around nets and controls, statistical tests were performed using standard parametric and nonparametric methods (Analysis of Variance [ANOVA] and Wilcoxon rank sum test; Zar, 1999). Power analysis was performed according to methods given in Cohen (1988) and Zar (1999).

Many technical problems with the data loggers occurred during the trials, resulting in considerable data loss. Of the 149 logger deployments, 112 (75%) contained noncorrupted data (56 files from PCLs at fishing nets and 56 files from PCLs at control stations). The technical problems with the data loggers corrupted the experimental paired design schedule, for which each data logger was supposed to be used in both gill net and control circumstances. Out of the data that could be analysed, there were 16 net and 18 control locations of noncorrupted pairs of deployments. Out of these files, there were 12 net and 12 control locations for which data from both treatments were collected on the same date; these were selected for further analysis.

The data from the loggers (expressed as "Encounters per 100 hours") are presented in Figure 3, where PCL1 and PCL2 are the two data loggers belonging to a single net/control site. As the acoustic activity of PCL1 and PCL2 are related (they fall quite close to the stippled line y = x in Figure 3, except for in one case from data collected with a net), this indicates that both data loggers may have detected the same harbour porpoises and that they thus have been working the way they were anticipated to perform.

There was no significant difference in the acoustic activity of harbour porpoises (measured as the number of encounters per 100 h of recordings) between the two loggers situated at each site, either for loggers with or without gill nets (ANOVA on log-transformed data to meet the requirements of normality and homoscedasticity, df = 11, $p > 0.05$). There was no significant difference for the average encounters per 100 h made at each site, with and without gill nets (ANOVA on log-transformed data to meet the requirements of normality and homoscedasticity, df = 11, $p > 0.05$). Given the number of degrees of freedom, the variance and mean values of the derived data, and assuming that an alternative hypothesis of a mean encounter rate as high as the maximum one observed in the trials, the power of the experiment was above 70%. In other words, the likelihood of finding a significant difference in harbour porpoise activity between net and control deployments, given such a difference exists, was more than 70%.

The intervals between harbour porpoise detections for trials with and without nets were compared. This comparison was made as another measure of any difference in the acoustic detections between controls and net deployments. A difference could either indicate a change in the number

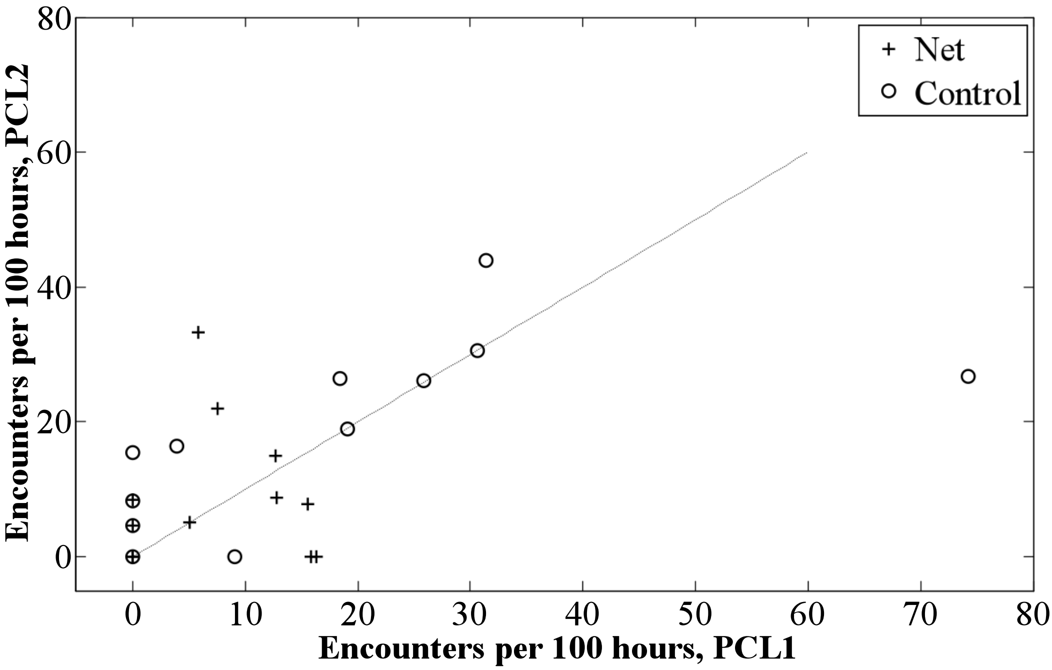

Figure 3. The number of acoustic encounters of harbour porpoises per 100 h for paired data loggers situated at fishing nets and control sites; each pair is represented by a PCL1 and a PCL2. PCL1 is the one having either the longest deployment time or, if both loggers have the same deployment time, then PCL1 is the logger which was deployed first.

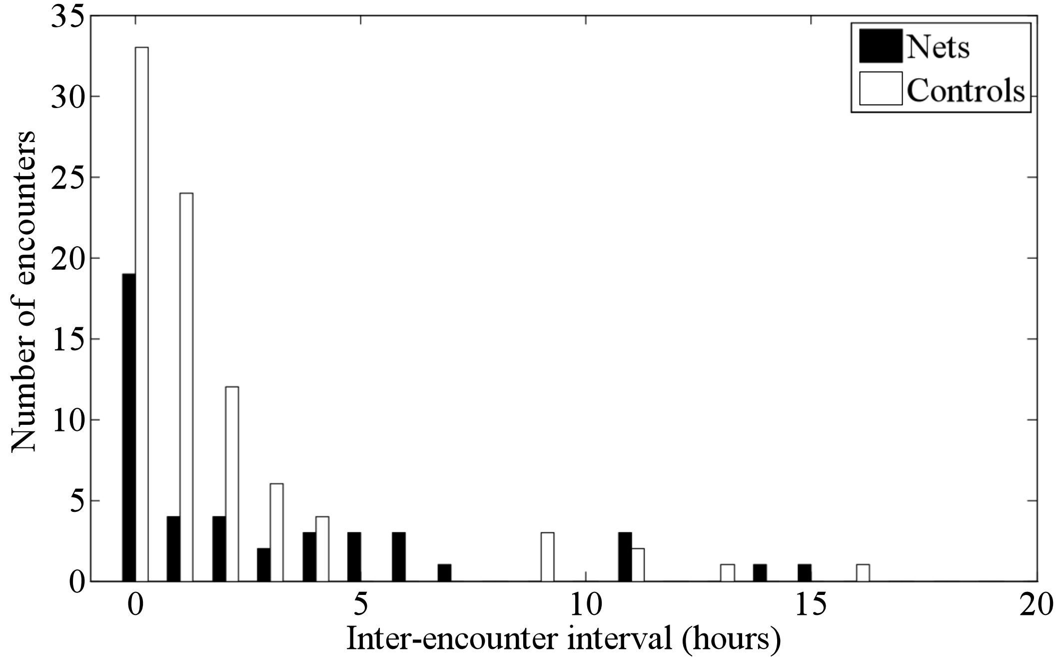

Figure 4. Inter-encounter interval histogram of all data from the Kattegat trials with and without gill nets

of harbour porpoises between the two treatments or a difference in the acoustic behaviour of harbour porpoises around nets compared to without nets. The intervals were not affected by the presence of the fishing net (Figure 4; Wilcoxon rank sum test, $df_1 = 86$ and $df_2 = 44$, $p > 0.05$). This strongly suggests that harbour porpoises do not actively approach fishing nets of any of the kinds used here. At the same time, there was no clear indication of the harbour porpoises being deterred by the net at long distances as has been observed in a recent study by Nielsen et al. (2012). However, the data loggers used in our study can detect harbour porpoises up to a distance of several hundred meters. Therefore, even though the harbour porpoises might have been deterred some 50 to 80 m away from the nets, as suggested by Nielsen et al., this may not have been detectable in the data collected herein as the detection distance in this study was longer.

Harbour porpoises may detect fishing nets using both visual and acoustic cues. The detection distances longer than a few meters can only be accomplished using acoustic cues (or visual cues above the water surface; Nielsen et al., 2012). Different net parameters, such as mesh size, twine size, height above the sea floor, type of float lines, and the hanging ratio (the length of the meshed net compared to the length of the float line), will all affect the strength of the echoes returning from the nets, and thereby the potential of the harbour porpoises to detect them acoustically. A difference in bycatch has been shown between sole and cod nets (Vinther, 1999), but not all studies report clear-cut differences in bycatch between different types of nets (Jefferson & Curry, 1994). Therefore, we believe that the results derived here may be valid for a broader variety of nets. It should be emphasized that the current study has the limitation that the click loggers can detect harbour porpoises from a longer distance, several hundred meters, than the harbour porpoises are assumed to detect the nets. Data on the details in the animals' behaviour around the nets therefore has to await future studies. Still, from our data, we can conclude that harbour porpoises were neither attracted to nor deterred from the nets as the duration of encounters did not differ between nets and controls.

As harbour porpoises are seemingly not actively approaching gill nets to find fish, it seems unlikely that acoustic alarms (pingers) will have a so-called dinner bell effect as observed with seals (Jefferson & Curry, 1994). This may be an important reason why pingers have been shown to be an efficient way to mitigate the harbour porpoise bycatch problem in some gillnet fisheries (Kraus et al., 1997; Larsen et al., 2002, 2013). More information on the behavioural reactions of harbour porpoises to fishing gear and pingers will be beneficial for the successful further developments of methods to mitigate the problem of bycatch in fisheries, both in terms of more efficient and low-cost pingers and fishing gear that is less prone to catch harbour porpoises.

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